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Characterization of Chirped Pump Four-Wave Mixing in Nonlinear Fibers using only Continuous-Wave-Lasers

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Abstract: We propose a novel fiber characterization method that reveals the four-wave mixing bandwidth for chirped pump operation, using two tunable continuous-wave-lasers. The method accurately predicts the bandwidth for optical time lenses with broadband multi-carrier input.

OCIS codes: (060.4370) Nonlinear optics, fibers; (190.4380) Nonlinear optics, four-wave mixing;

1. Introduction and principle

The time lens [1], based on four-wave mixing (FWM) in highly nonlinear fiber (HNLF) [2], using chirped, flat-top pump pulses to, e.g., perform the optical Fourier transformation [3], is a versatile tool for advanced optical signal processing [4]. However, thus far no systematic characterization procedures for the optimization of such time lenses have been demonstrated. The continuous-wave- (CW) and pulsed-pump FWM bandwidth may differ greatly depending on the fiber properties and pump bandwidth [5], and standard CW-characterizations may be insufficient.

In this paper, we demonstrate a simple technique, which characterizes the bandwidth and conversion uniformity in different HNLFs, for optical Fourier transformations performing WDM to optical time-division multiplexing (WDM-OTDM) conversion. The principle behind WDM-OTDM conversion is illustrated spectrographically in Fig. 1(a), where WDM channels at frequencies ω_{si} are converted to chirped idlers at ω_{ii} , by FWM with chirped pump pulses of bandwidth $\Delta\omega_p$ at frequency ω_p , followed by dispersion to compress and evenly distribute the idler pulses in time. The proposed characterization technique exploits that the local temporal pump spectral content is in the narrowband compared to the total bandwidth. WDM channels typically have low symbol rates, hence the FWM process can be regarded as a series of concurrent, narrowband pump-signal interactions. The process efficiency may then be approximated by the summation of idler efficiency measurements using a CW pump swept over the time lens pump bandwidth, for CW signals centered on each of the WDM channel wavelengths, thus capturing the phase mismatch changes. In Fig. 1(a) the CW signal, pump and corresponding idler positions are indicated by circles. Here it is emphasized that only the spectral content of the pump overlapping with the signal, $\delta\omega_p$, should be considered.

2. Experimental setup, results and discussion

The HNLF characterization setup for FWM using a chirped pump, is shown in Fig. 1(b). The pump is generated from a tunable CW laser source (TLS), which is phase modulated to suppress stimulated Brillouin scattering. The signal is a TLS, coupling -6 dBm with the pump into the fiber-under-test (FUT). Finally, the FWM spectrum is

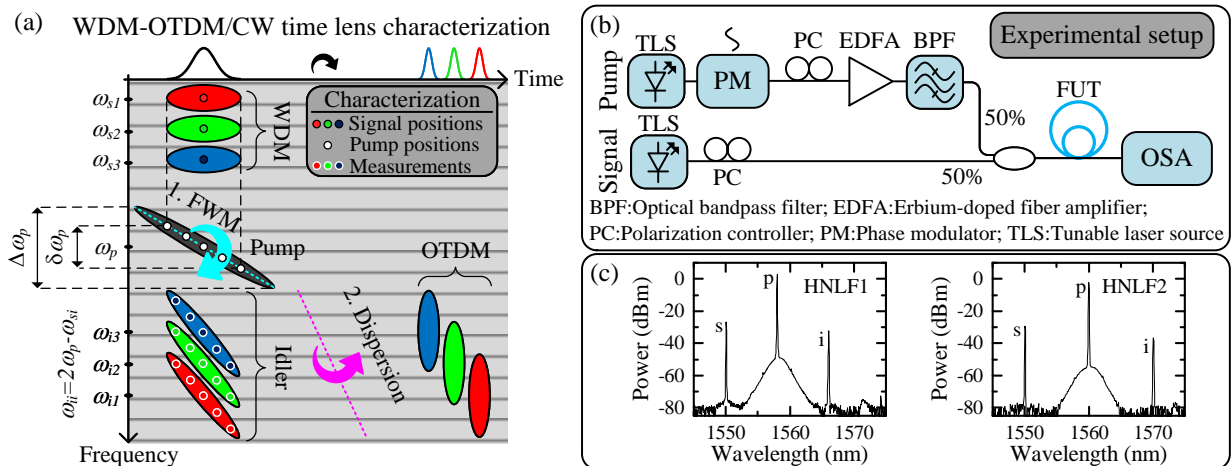


Fig. 1. (a) Principle of WDM-OTDM using a FWM-based time lens and dispersion, with indicated signal, pump and idler frequency positions (circles) to characterize the time lens bandwidth using only CW lasers. (b) Experimental characterization setup. (c) Sample FWM spectra.

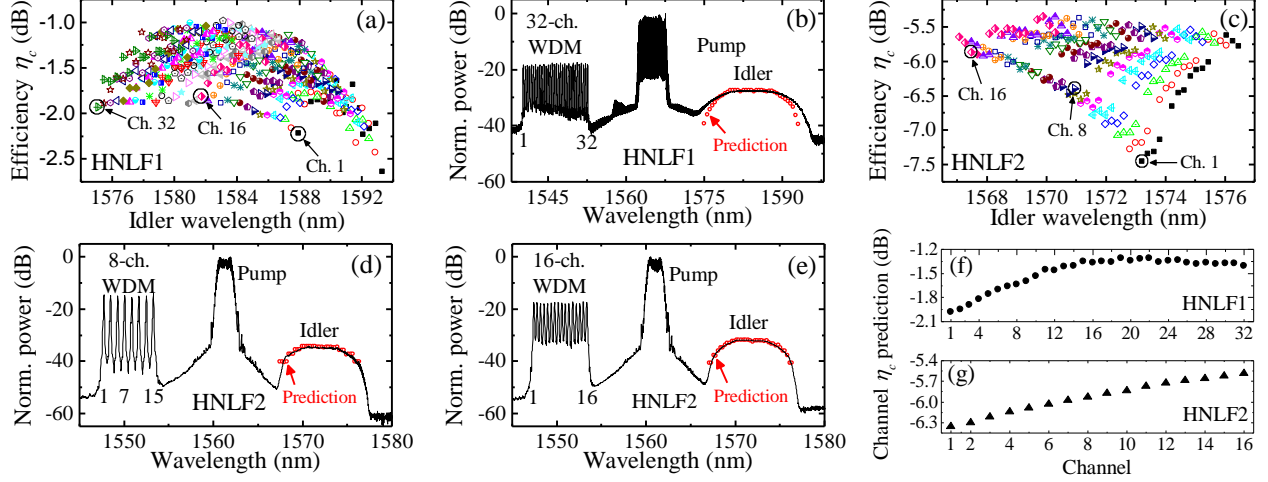


Fig. 2. (a), (c) Conversion efficiency at channel wavelengths with pump swept over $\delta\omega_p$. (b), (d), (e) OTDM-WDM time lens spectra with predicted idler spectrum based on measured CW data superimposed (circles) and (f), (g) estimated relative channel conversion efficiencies.

measured. There are two FUTs: HNLF1, which is a composite dispersion-flattened HNLF with length $L = 315$ m, zero dispersion wavelength $\lambda_0 = 1560.4$ nm, slope $S = 0.005$ ps/(nm²·km) and nonlinear coefficient $\gamma = 10.8$ (W·km)⁻¹, and HNLF2, which is a standard HNLF with $L = 500$ m, $\lambda_0 = 1561$ nm, $S = 0.017$ ps/(nm²·km) and $\gamma = 11.3$ (W·km)⁻¹. HNLF1 was used for WDM-OTDM conversion of 32 channels with 50 GHz spacing using a pump centered at 1565 nm with ~4.8 nm 1-dB bandwidth, and rectangular pulses with 75% duty cycle (DC) and 25 dBm average power [6]. HNLF2 was used in an experiment for the conversion of 8 and 16 channels with 100 GHz and 50 GHz spacing respectively, using a pump centered at 1561 nm with ~1.6 nm 1-dB bandwidth, 55% DC and 17.5 dBm average power [7]. Sample CW FWM output spectra for the HNLFs are shown in Fig. 1(c). For HNLF1 the pump was tuned in steps of 0.2 nm over $\delta\omega_p = 2.6$ nm (40% WDM DC) with 26.3 dBm power (~pulsed peak power) for each of the 32 channel wavelengths. The input conversion efficiencies, η_c , are shown for each channel in Fig. 2(a). The sum of the efficiency curves is superimposed on the corresponding time lens FWM spectrum in Fig. 2(b), showing good agreement, with a 3-dB bandwidth error of 16%. For HNLF2 the pump was tuned in steps of 0.1 nm over $\delta\omega_p = 1.6$ nm with 20.1 dBm power, for each of the 16 channel wavelengths. The resulting efficiency spectra are shown in Fig. 2(c). In Fig. 2(d) the superimposed estimation using data for 8 channels shows extremely good agreement with the time lens FWM idler, and negligible error. Similarly, the results for 16 channels, shown in Fig. 2(e), predicts the shape of the output idler spectrum with high accuracy. The per-channel efficiencies were estimated as the average of the data points for each channel (cf. Fig. 2(a), (c)), shown in Fig. 2(f) and Fig. 2(g). The channel conversion uniformity is estimated to be 0.6-0.7 dB for the fibers. For the HNLF1 experiment the difference between channels 1 and 32 was ~0.8 dB, indicating that reasonable estimates are obtained, although the absolute values differ by ~2.3 dB. It was found that using short pump step sizes enables the prediction of small features, but coarse step sizes (~0.5 nm) to reduce the number of measurements, may be sufficient for bandwidth estimation.

3. Conclusion

We have proposed a simple method for bandwidth characterization of FWM with chirped pump pulses in HNLFs using only two tunable CW lasers. Accurate bandwidth estimates for the conversion of WDM signals in optical time lenses were obtained, and hence the method shows promise as a tool for the optimization of such systems.

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